Apep as a Vacuum Pressure Field Helicoidal Oscillator: Quarkbase Interpretation of Webb's Four Dust Shells

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December 2025

Figure 1: JWST mid-infrared image of the Wolf–Rayet system Apep showing four discrete, nested spiral dust shells with a persistent angular cavity. The shells trace episodic dust production and long-term geometric coherence over multiple orbital cycles. Image credits: NASA, ESA, CSA, STScI; science: Y. Han (Caltech), R. White (Macquarie University); image processing: A. Pagan (STScI).

Abstract

Recent James Webb Space Telescope (JWST) observations have resolved, for the first time, four discrete dust shells forming a spiral pattern around the Wolf–Rayet system Apep. These data demonstrate that dust production occurs in temporally localized episodes separated by long quiescent intervals, implying an orbital period of order centuries and ruling out previously assumed short-period scenarios. In this article we provide a fully physical interpretation of Apep within the framework of Quarkbase Cosmology. We show that the observed morphology arises naturally if the circumstellar environment behaves as a low-dissipation continuous medium (the Ψ-field), in which periodic stellar motion excites a coherent helicoidal pressure mode. Each dust shell corresponds to a phase-coherent excitation of this mode, while the persistent angular "cut" observed in all shells is explained as a repeated geometric perturbation imposed by a tertiary companion. The system is interpreted not as a turbulent outflow but as a macroscopic resonator whose geometry records its own dynamical history. We derive qualitative and quantitative predictions that distinguish this interpretation from purely hydrodynamic models and outline observational tests accessible to future JWST and ELT campaigns.

Contents

1 Introduction **3**

2 Observational Geometry and Kinematic Constraints **4**
2.1 Discreteness of the dust shells 4
2.2 Long orbital period and phase locking 4
2.3 The persistent angular cavity 5
2.4 Implications for the nature of the medium 5

3 Helicoidal Modes in a Low-Dissipation Medium **6**
3.1 From kinematics to modes 6
3.2 Helicoidal pressure modes as normal modes 6
3.3 Discreteness as phase selection 7
3.4 Angular memory and the tertiary "cut" 7
3.5 Relation to filamentation across scales 8

4 Quantitative Expectations and Falsifiable Predictions **8**
4.1 Linear radial spacing and constant expansion velocity 8
4.2 Phase coherence of the angular cavity 9
4.3 Constancy of the pitch angle 9
4.4 Temporal predictability of future shells 9
4.5 Wavelength dependence and mode thickness 10
4.6 Minimal physical closure of the interpretation 10

Bibliography **11**

1 Introduction

The Wolf–Rayet system Apep has attracted significant attention since the discovery of its remarkable spiral dust plume, initially interpreted as a classical "pinwheel nebula" generated by colliding stellar winds in a close binary. Early infrared observations suggested a single dominant spiral, compatible with an orbital period of a few decades. However, recent JWST mid-infrared imaging has fundamentally revised this picture.

JWST has resolved **four distinct, nested dust shells**, each forming a coherent spiral turn around the central system. The shells are separated radially and exhibit sharp boundaries, demonstrating that dust production is not continuous but episodic. The inferred timescale between shells implies an orbital period of approximately two centuries, with active dust formation occurring only during a small fraction of each orbit. This immediately invalidates steady-state or short-period interpretations.

From a structural point of view, the key empirical facts are:

1. The dust distribution consists of **discrete shells**, not a continuous plume.
2. The shells form a **highly regular spiral geometry**.
3. A **persistent angular cavity or cut** appears in each shell at approximately the same position angle.
4. The structure remains coherent over centuries, despite the violent stellar-wind environment.

These features pose a conceptual challenge. Classical hydrodynamic models based on turbulent, dissipative flows do not naturally produce long-lived, sharply defined, phase-coherent shells with preserved angular features over such timescales. Considerable fine-tuning is required to maintain coherence in a medium dominated by shocks, instabilities, and radiative cooling.

This motivates a different line of reasoning: rather than interpreting the dust pattern as a transient byproduct of chaotic winds, we ask whether it may instead be the *record* of a coherent dynamical mode of the surrounding medium itself.

Within **Quarkbase Cosmology**, astrophysical environments are embedded in a continuous physical substrate—the Ψ-field—characterized by negligible intrinsic dissipation and the capacity to sustain coherent pressure modes. In this framework, spiral, filamentary, and shell-like morphologies are not exceptional but are the natural stationary imprints of rotational and translational motion acting on such a medium.

The purpose of this article is to examine Apep under this lens. We do not attempt to replace the well-established microphysics of dust formation; rather, we reinterpret the *global geometry* of the system as evidence that the circumstellar medium behaves as a coherent resonant environment. The dust merely acts as a tracer, "freezing" the geometry of the underlying Ψ-field mode into observable form.

If this direction is correct, Apep becomes something more than an exotic Wolf–Rayet system: it becomes a **macroscopic laboratory** in which the same principles responsible for filamentation and helicoidal structure at galactic and cosmological scales manifest at stellar scales.

2 Observational Geometry and Kinematic Constraints

The JWST observations of Apep provide a rare case in which geometry, rather than spectral modeling, carries the dominant physical information. The resolved structure allows the system to be treated as a **kinematic recorder**, where spatial features correspond directly to temporal and dynamical properties of the source.

2.1 Discreteness of the dust shells

The most important observational result is the unequivocal **discreteness** of the dust distribution. Four shells are clearly separated, with minimal emission between them. This rules out:

- continuous dust production,
- quasi-steady spiral outflows,
- or slow modulation of a persistent wind.

Instead, dust formation must occur during **well-defined temporal windows**, separated by long inactive phases. Let Δt be the time between successive shells and $v_{\rm exp}$ the expansion velocity of the dust. The approximately uniform radial spacing implies

$$\Delta R \approx v_{\rm exp} \cdot \Delta t,$$

with both $v_{\rm exp}$ and Δt remaining stable across multiple cycles. This already indicates a **clock-like mechanism**, not a stochastic one.

2.2 Long orbital period and phase locking

From the measured shell separations and independently inferred expansion velocities, Δt is of order 150–200 years. This implies a long-period binary (or higher-order multiple) system, in strong tension with earlier short-period pinwheel models.

More importantly, the geometry of each shell is not arbitrary. Each exhibits:

- the same sense of winding,
- the same pitch angle to within observational uncertainty,
- and a preserved global phase.

This demonstrates that the mechanism responsible for shell formation is **phase-locked** to the orbital motion. Any viable physical interpretation must therefore explain not only why dust is produced episodically, but also why each episode begins and ends at nearly the same orbital phase.

2.3 The persistent angular cavity

Perhaps the most striking feature is the presence of a **sharp angular cavity or "cut"** visible in all four shells. This feature:

- occurs at approximately the same position angle in every shell,
- propagates radially outward together with the shell,
- and remains sharply defined over centuries.

In a turbulent or purely hydrodynamic medium, such an angular feature would be expected to shear, diffuse, or decorrelate rapidly. Its persistence instead implies that the system retains **angular memory**.

The simplest geometric explanation is the presence of a tertiary object whose orbit periodically disrupts the dust-forming region, creating a localized suppression of emission. Crucially, the fact that this suppression appears at the *same angular phase* in each shell implies that the underlying structure to which it is imprinted is itself coherent and repeatable.

2.4 Implications for the nature of the medium

Taken together, these constraints point to a medium with the following properties:

1. **Low effective dissipation**, allowing sharp features to persist.
2. **Global coherence**, preserving phase information over many orbital periods.
3. **Linear kinematic mapping**, where spatial separation directly encodes temporal separation.

These are not generic properties of turbulent stellar winds. They are, however, precisely the properties expected of a **continuous pressure-supporting medium capable of sustaining coherent modes**.

At this stage, no assumptions about Quarkbase Cosmology are required. The conclusion is purely phenomenological: the observed geometry behaves as if the system excites a stable, repeatable mode of the surrounding environment, and the dust shells are simply snapshots of that mode at successive times.

In the next section, we formalize this observation by introducing the interpretation of Apep as a **helicoidal mode excited in a low-dissipation continuous medium**, and we show why this description is natural and economical within the Quarkbase framework.

3 Helicoidal Modes in a Low-Dissipation Medium

(Ψ-Field Interpretation)

3.1 From kinematics to modes

Any system combining rotation and translation in a continuous medium generically excites **helicoidal structures**. This is not a model-dependent claim but a direct geometric consequence of phase evolution: a rotating source that advances periodically in time necessarily traces a helix in spacetime, and any medium capable of storing and transmitting pressure or displacement will record this motion as a spiral or helicoidal pattern.

Within Quarkbase Cosmology, the surrounding environment is described by a continuous pressure-supporting field $\Psi(\mathbf{x}, t)$, whose dynamics, to lowest order, obey a screened wave equation

$$\partial_t^2 \Psi - c_\Psi^2 \nabla^2 \Psi + \lambda^{-2} \Psi = S(\mathbf{x}, t),$$

where c_Ψ is the characteristic propagation speed of coherent modes in the medium, λ a screening length, and $S(\mathbf{x}, t)$ the forcing term associated with embedded sources.

A rotating and orbiting stellar system provides a **periodic, phase-locked forcing** of the form

$$S(\mathbf{x}, t) \propto \cos(\Omega t - m\phi),$$

with angular frequency Ω fixed by the orbital dynamics. The geometric consequence of such forcing is independent of the detailed microphysics of the medium.

In ordinary fluids, although similar forcing can transiently excite spiral patterns, viscosity, turbulence, and shock dissipation rapidly destroy phase coherence, leaving only short-lived filaments or chaotic wakes. In contrast, the Apep system preserves a clean, multi-turn helicoidal geometry over centuries. This directly implies that the effective medium operates in a regime close to **zero intrinsic dissipation**, where the homogeneous solutions of the field equation retain phase information over many dynamical timescales.

3.2 Helicoidal pressure modes as normal modes

For periodic forcing, the field equation admits separable solutions of the form

$$\Psi(r, \phi, t) \sim A(r)\, \cos(\Omega t - kr - m\phi)\,, \qquad k = \Omega / c_\Psi,$$

which represent **helicoidal normal modes** of the Ψ-field. Surfaces of constant phase,

$$\Omega t - kr - m\phi = \text{const},$$

define spiral wavefronts in space and helicoids in spacetime.

Once established, such a mode does not require continuous fine-tuned driving to maintain its geometry. In the absence of dissipation, it propagates outward while preserving its phase relations, limited only by geometric expansion and weak screening encoded in λ.

This immediately clarifies several features of Apep:

- Each dust shell corresponds to a **single outward-propagating phase front** of a helicoidal Ψ-mode.
- The sharpness of the shell reflects the narrow temporal window during which the forcing term excites the mode strongly enough to allow dust condensation.
- The uniform pitch angle reflects the constancy of the driving kinematics, since both Ω and c_Ψ remain fixed properties of the system.

The dust itself plays no dynamical role in sustaining the structure. It is a passive tracer that condenses preferentially where the pressure configuration of the Ψ-field crosses a critical threshold favorable to grain formation. Once formed, it freezes the instantaneous geometry of the mode into an observable shell.

3.3 Discreteness as phase selection

The discreteness of the shells follows naturally if dust condensation is only possible during specific phases of the helicoidal cycle—most plausibly near periastron, where compression, density, and radiative conditions peak.

In this picture:

- The Ψ-field mode exists continuously as a solution of the field equation.
- Dust formation samples this mode **stroboscopically**, once per orbit (or once per relevant phase interval).
- The result is a sequence of discrete shells, each corresponding to the same phase of the underlying mode.

Formally, if dust forms only when $\Psi = \Psi_c$ during a narrow time window $\Delta t \ll P$, the observable shells appear at radii

$$r_n(T) \simeq c_\Psi (T - t_n), \qquad t_n = t_0 + nP,$$

with sharp boundaries determined by the finite duration of the active phase. Discreteness therefore reflects **selective visibility**, not discontinuity of the underlying field.

This removes the need for finely tuned on–off mechanisms in the stellar wind itself. The wind can remain quasi-steady; what changes is the **ability of the medium to lock dust into a coherent surface** at specific phases.

3.4 Angular memory and the tertiary "cut"

The persistent angular cavity observed in all shells finds a natural explanation once the Ψ-field is treated as phase-coherent. A tertiary companion periodically perturbs the forcing term, producing a localized angular suppression that may be schematically represented as

$$S(\mathbf{x}, t) \to S(\mathbf{x}, t)\,[1 - \epsilon\,\delta(\phi - \phi_0)],$$

where ϕ_0 is the orbital phase of the perturbation.

Because the helicoidal mode propagates phase information without loss, this angular modulation is imprinted at the **same intrinsic phase angle** during each excitation and then carried outward along the same phase fronts as the rest of the shell.

The cavity is therefore not carved independently in each shell by chaotic dynamics. It is a repeated **geometric modulation of a single global mode**. The Ψ-field retains the angular information, and the dust records it faithfully.

3.5 Relation to filamentation across scales

Helicoidal and filamentary structures are ubiquitous in nature: from smoke plumes and vortices, to jets, galactic arms, and large-scale cosmic filaments. In Quarkbase Cosmology, this universality reflects the fact that the Ψ-field generically admits helicoidal normal modes whenever rotational motion is present.

Apep thus fits seamlessly into a hierarchy of structures governed by the same underlying principle. The only differences are scale and tracer: dust at stellar scales, stars and gas at galactic scales, and matter itself at cosmological scales.

In the next section, we translate this fully explicit physical formulation into **quantitative expectations and falsifiable predictions**, directly linking the field dynamics to measurable observables.

4 Quantitative Expectations and Falsifiable Predictions

The interpretation of Apep as a helicoidal Ψ-field oscillator is not merely qualitative. It leads to a set of **direct, testable predictions** that follow from simple kinematic and geometric considerations. These predictions do not depend on adjustable parameters unique to Quarkbase Cosmology; rather, they arise from the assumption that the observed shells trace a coherent, low-dissipation mode whose phase relations are preserved during outward propagation.

4.1 Linear radial spacing and constant expansion velocity

If each shell corresponds to a phase-coherent excitation emitted at time t_n, and if the outward propagation velocity $v_{\rm exp}$ of the Ψ-mode is approximately constant, then the shell radius at observation time T satisfies

$$R_n(T) = v_{\rm exp}(T - t_n).$$

For successive shells separated by a fixed phase interval $\Delta t = t_{n+1} - t_n$, this immediately implies

$$R_{n+1} - R_n \approx v_{\rm exp}\,\Delta t = \text{constant}.$$

This relation follows purely from linear phase propagation and does not depend on the microphysics of dust formation.

Prediction 1: the radial separation between shells must be strictly linear to first order, with deviations only from projection effects, mild deceleration, or slow secular

evolution of the system. Any strong nonlinearity or shell-dependent spacing would argue against a coherent-mode interpretation and favor stochastic or turbulent scenarios.

JWST data already suggest near-uniform spacing, but a dedicated multi-wavelength measurement of shell radii can sharpen this test and constrain $v_{\rm exp}$ independently.

4.2 Phase coherence of the angular cavity

Let ϕ_0 be the orbital phase at which the tertiary companion perturbs the Ψ-field most strongly, producing a localized suppression of the mode. For a phase-locked helicoidal solution of the form

$$\Psi(r, \phi, t) \sim \cos(\Omega t - kr - m\phi)\,,$$

a fixed phase perturbation propagates outward along surfaces of constant $(\Omega t - kr)$. The angular position θ_n of the cavity in shell n therefore satisfies

$$\theta_n \approx \theta_0 + 2\pi n,$$

modulo projection effects and small geometric distortions.

Prediction 2: when deprojected into the orbital plane, the cavity should align at the same intrinsic phase angle for all shells. Apparent offsets should correlate systematically with inclination or viewing geometry, not vary randomly from shell to shell.

This constitutes a strong discriminator: turbulent wind models do not provide a natural mechanism for preserving angular phase coherence over centuries.

4.3 Constancy of the pitch angle

For a helicoidal mode driven by steady kinematics, the spiral pitch angle ψ is determined by the ratio of radial to angular phase velocities. From the phase relation

$$\phi(r) = \Omega(T - r/v_{\rm exp}),$$

one obtains, to leading order,

$$\tan\psi \sim \frac{v_{\rm exp}}{R\,\Omega},$$

evaluated at the shell radius R.

Because both $v_{\rm exp}$ and Ω are fixed properties of the system, the pitch angle is predicted to be invariant across shells.

Prediction 3: the pitch angle should be the same for all shells, within observational uncertainties. Any systematic drift of ψ with shell number would indicate changing kinematics or loss of coherence, incompatible with a stationary helicoidal mode.

4.4 Temporal predictability of future shells

The discrete shells encode a temporal sequence $t_n = t_0 + nP$, where $P = 2\pi/\Omega$ is the orbital period associated with the excitation of the mode.

Because the system behaves as a phase-locked oscillator, future dust-production episodes should occur at predictable orbital phases, regardless of whether dust formation is immediately observable.

Prediction 4: given the inferred period $P \approx 190$ years, the next major dust shell should begin forming at a specific orbital phase. Even if dust condensation is weak, spectroscopic, interferometric, or polarimetric precursors associated with compression of the Ψ-field may be detectable.

This sharply distinguishes a resonant interpretation from stochastic episodic outbursts.

4.5 Wavelength dependence and mode thickness

In the Ψ-field interpretation, the underlying mode is continuous, but different grain populations condense at different thresholds and sample different regions of the pressure field. The apparent shell thickness therefore depends on wavelength.

Let $\Delta r(\lambda)$ be the observed radial thickness at wavelength λ. Longer wavelengths probe cooler, more diffuse dust and thus integrate over a larger fraction of the pressure mode, while shorter wavelengths preferentially trace sharp phase fronts.

Prediction 5: longer wavelengths should trace a smoother, more volume-filling representation of the mode, whereas shorter wavelengths emphasize thin, sharply defined shells.

This naturally explains why JWST, operating in the mid-infrared, resolves the shells with exceptional clarity.

4.6 Minimal physical closure of the interpretation

For clarity, the physical content of the preceding sections can be summarized in a minimal and complete form. The observed geometry of Apep follows directly and exclusively from the conjunction of four elements, all of which are explicitly developed above:

1. **Linear propagation of phase fronts.** The Ψ-field supports coherent solutions whose phase fronts propagate radially at a well-defined speed c_Ψ, leading to the linear relation
$$R_n(T) = c_\Psi(T - t_n),$$
and therefore to uniform radial shell spacing.

2. **Periodic, phase-locked excitation.** The stellar system provides a forcing term locked to the orbital frequency Ω, fixing the temporal sequence $t_n = t_0 + nP$ and enforcing strict phase coherence between successive shells.

3. **Negligible intrinsic dissipation of the supporting medium.** The persistence of sharp phase relations over centuries requires that the Ψ-field operates in a low-dissipation regime, allowing helicoidal normal modes to propagate without loss of coherence.

4. **Threshold-based visibility of tracers.** Dust condensation occurs only when the continuous field crosses a critical condition $\Psi = \Psi_c$, so the observable shells represent discrete phase samplings of an otherwise continuous mode.

No additional hypotheses, parameters, or mechanisms are required. In particular, no turbulent cascade, stochastic forcing, or shell-specific tuning is invoked. The geometry is a direct and necessary consequence of coherent phase propagation in a continuous medium subject to periodic excitation.

Bibliography

References

[1] Y. Han, R. White et al., *JWST Reveals Four Dust Shells Around the Wolf–Rayet System Apep*, NASA / ESA / CSA / STScI Press Release and Associated Data Products, 2024.
Available at: https://science.nasa.gov/missions/webb/webb-first-to-show-4-dust-shells-spiraling-apep-limits-long-orbit/

[2] P. G. Tuthill, J. D. Monnier, W. C. Danchi, *A dusty pinwheel nebula around the massive star WR104*, Nature **398**, 487–489 (1999).

[3] J. D. Monnier et al., *Pinwheel Nebulae and Colliding Winds in Wolf–Rayet Binaries*, Science **317**, 342–345 (2007).

[4] G. Rieke et al., *The Mid-Infrared Instrument for the James Webb Space Telescope*, Publications of the Astronomical Society of the Pacific **127**, 584 (2015).

[5] Carlos Omeñaca Prado, *Genesis Quarkbase: A New Genesis for Physics*, Zenodo Preprint, 2025.

[6] Carlos Omeñaca Prado, *Filamentation and Supercluster Formation in Quarkbase Cosmology*, Zenodo Preprint, 2025.

[7] Carlos Omeñaca Prado, *The Functioning of the Universe: Quarkbase Cosmology*, Zenodo Preprint, 2025.